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The Dynamic Structure of Navy Research and Development Budgets: A Time-Series Analysis

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This paper investigates the dynamic nature of the Navy's R&D budget by examining the Navy's budget in the aggregate and by functional activity (i.e., manpower, operation and maintenance, procurement, and research and development). Qualitative conclusions about trends in each functional area are made using constant-dollar plots for the period 1955-88. The percentage of the aggregate DON budget that is allotted to R&D has been remarkably constant at 10 percent over the last 30 years. A forecast for the R&D budget percentage is made for the next 5 years using statistical techniques. Thus, independent forecasts of the aggregate DON budget can be used to generate alternative R&D budget forecasts.

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INTRODUCTION

In response to tasking from OP-98, CNA recently reviewed technology initiatives that will support the development of Navy systems[1] into the middle of the 21st century. The ultimate goal of this effort, Quo Vadis (Phase II), was to present OP-98 with an investment strategy that minimizes unevenness in Navy research and development expenditures over time and is consistent with projections of future R&D funding.

Any meaningful investment strategy must respond to the requirement of affordability. It obviously is not very helpful to the Navy for Quo Vadis to propose future R&D investments that have no relation to available funds. Therefore, the success of the Quo Vadis effort depends to some extent on projecting research and development budgets into the relatively distant future. Given that any such projection inevitably will be inaccurate to some degree, and that forecast errors generally increase with the length of the forecast period, it becomes important to understand as well as possible the dynamic pattern of budget growth over time.

This paper represents a preliminary attempt to investigate the dynamic behavior of the Navy R&D budget by examining it in the aggregate and by functional activity (i.e., manpower, operation and maintenance, procurement, and research and development). The goal of this analysis is to determine how sophisticated an acceptable model of R&D expenditures must be in order to be useful. While there is always a tendency to opt for the simplest possible model, such models should be used only when the available data suggest that more sophisticated models are not required. At a first order of approximation the candidate models are, in order of sophistication[2]:

- Straight-line extrapolation of most recent year (in constant dollars)
- Constant rate of growth
- Time-series models of budget series
- Structural models of budget series.

Because time-series models are the simplest of the statistical models among these alternatives, they are an especially useful tool for discerning the time structure of DON budgets. Therefore, this paper is based primarily on a preliminary

1. Throughout this paper, the term "Navy" will be understood to mean the Department of the Navy, i.e., the U. S. Navy and Marine Corps, including both active-duty and reserve forces.
2. Assuming that the entire R&D budget request always will be funded is taken to be inadmissible as a model.

ime-series analysis of Navy R&D budgets. The first section graphically presents recent U. S. Navy budget data to provide background for subsequent discussion. Second, some basic elements of economic time-series modelling are presented, and their implications for the specification of forecasting models are discussed. Third, a forecast is given for the R&D budget series.

GRAPHICAL ANALYSIS OF NAVY BUDGETS BY FUNCTION

Each functional component of the Navy budget has grown significantly in constant dollar terms since the 1950s. Figure 1 shows the Navy's aggregate budget for the period 1955-1988, in constant dollars.[1] (Data for all figures are included in the appendix.) Qualitatively, two trends are evident from figure 1: a temporary increase in real expenditures during the Vietnam period (1966-1972), and a dramatic increase in real expenditures after 1981.

However, these trends do not necessarily represent movements in each of the functional budgets. Figure 2 shows Navy manpower budgets over this period. Probably the most significant event during this period was the dramatic increase in real cost per active-duty member during the early 1980s. Between 1981 and 1988, the Navy manpower budget increased by approximately 80 percent, from $5.1 billion to $9.7 billion. During this same period, endstrength increased by only about 20 percent.[2]

Navy operation and maintenance (O&M) budgets, on the other hand, display a somewhat different pattern, shown in figure 3. O&M certainly increased during the Vietnam era, and also after 1981. But additionally, O&M expenditures jumped considerably during the mid-1970s, probably reflecting fuel price increases. Finally, there is some suggestion from figure 3 that O&M budgets exhibit some cyclic behavior over time.

Figure 4 shows that procurement expenditures historically have exhibited pronounced peaks and troughs over time. The large peak in the early 1960s represents construction of the first large strategic submarine fleet. Another peak occurs during the Vietnam period, and primarily comprises replacement aircraft. Procurement went into a significant decline through the mid-1970s, rebounding slightly at the end of the decade. Finally, procurement increased dramatically after 1981.

The Navy RDT&E budget, which is of greatest importance for this study, is presented in figure 5. As one might expect, the Navy RDT&E budget appears

1. Constant dollars are expressed in terms of 1972 dollars, which is the midpoint of the date range covered by the data. Use of beginning or ending years as a base has the undesirable feature of artificially increasing or decreasing the apparent amplitude of the time series.

2. The remaining 60 percent of this increase is primarily accounted for by two factors: (1) increasing seniority among active-duty personnel, as a result of the success of various ret ion measures undertaken in the late 1970s, and (2) the FY 1984 change in military retirement funding

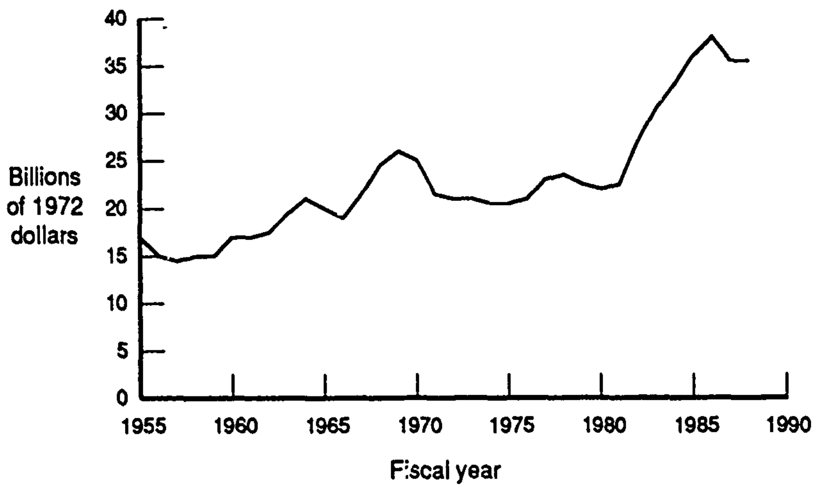

Figure 1. Total DON budget, 1955-1988

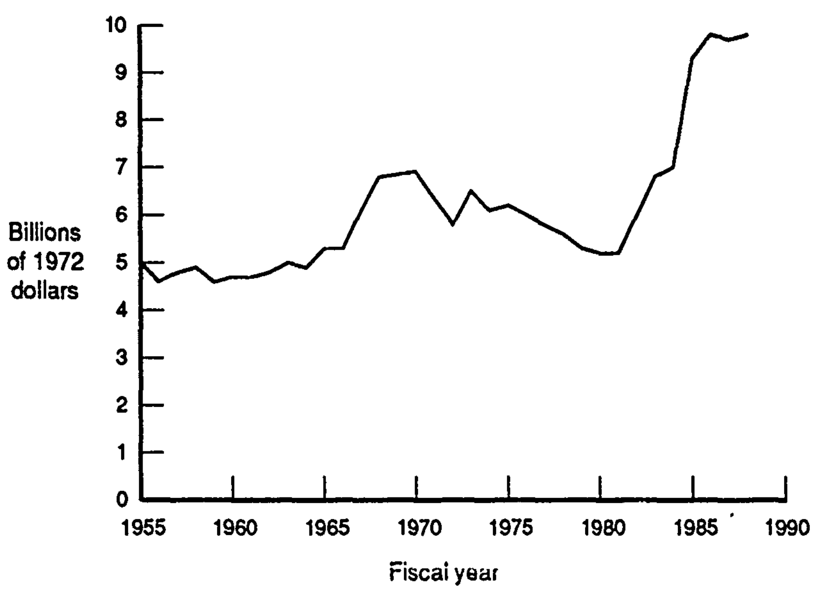

Figure 2. DON manpower budget, 1955-1988

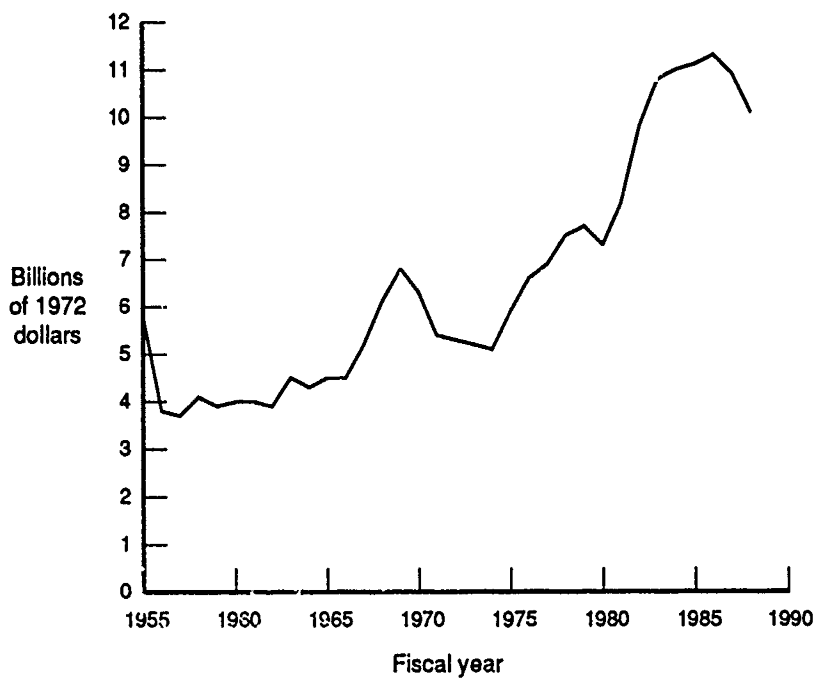

Figure 3. DON operations and maintenance budget, 1955-1988

Figure 4. DON procurement budget, 1955-1988

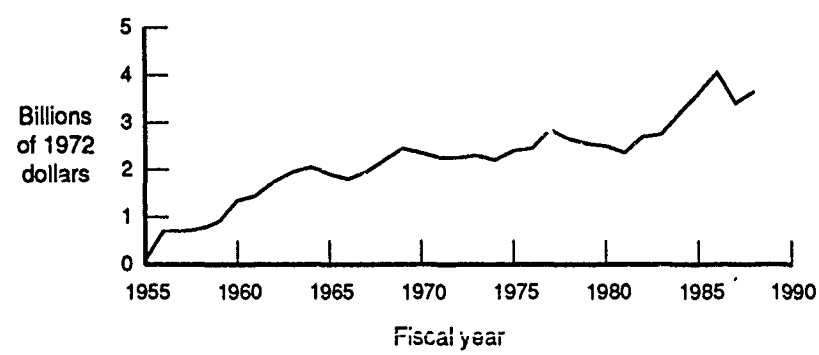

Figure 5. DON research and development budget, 1955-1988

much less sensitive to external events than the other functional budgets. In constant dollars, RDT&E has increased over time at a fairly constant rate of 5 percent per year since the mid-1960s. The Reagan administration jump in DON budgets seems not to have translated into a jump in the research and development budget until after 1984.

Despite these trends in the component budgets, however, the total budget shares of each function have remained remarkably constant over time. Figure 6 shows the functional composition of the total DON budget. Procurement has remained more or less a constant share of the budget, with manpower ·d O&M each occasionally gaining or losing a bit at the other's expense. However since the early 1960s, R&D has absorbed a steady 10 percent of the overall DON budget. Anecdotal evidence suggests that the Navy has long had a "10 percent" programming policy for research and development.

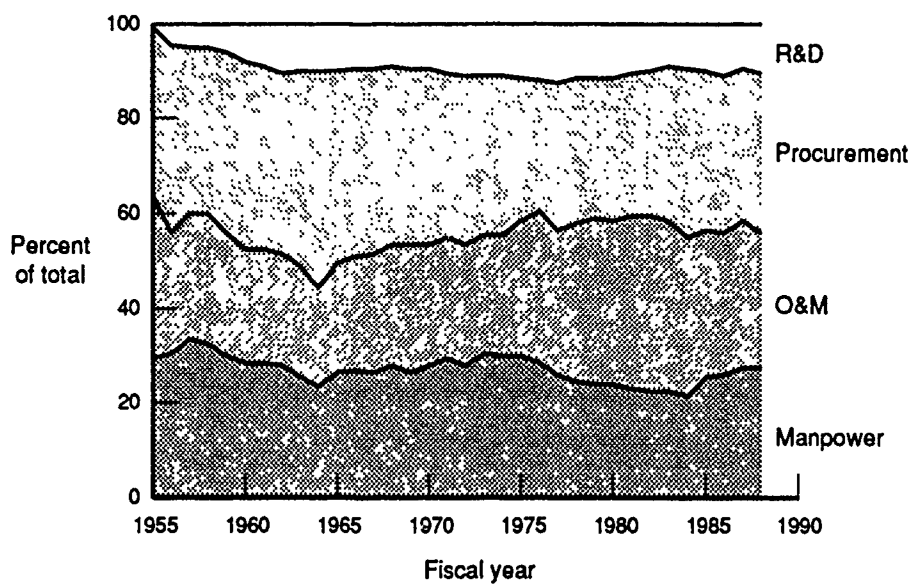

Figure 6. Functional composition of DON budget, 1955-1988

What are the implications of these figures? Recognizing that more formal statistical analysis is required to investigate the structure of these time series, it is still possible to make the following qualitative points:

- The research and development budget is not particularly sensitive to major external events.

- The procurement budget seems to be most sensitive to transitory events (e.g., wars and changes of administration) and also to major systems developments (e.g., construction of submarines).
- The O&M budget appears to grow at a fairly constant, rate except when interrupted by major external events (e.g., wars, oil price increases).
- The manpower budget tends to reflect force levels.

The following section proposes a statistical model for investigating these qualitative impressions further with respect to the R&D budget.

TIME-SERIES MODELS OF NAVY BUDGETS

There essentially are two kinds of economic models that can be specified for budget profiles: time-series models and structural models. Time-series models are simpler in that only the behavior of the budget (or other economic) variable over time need be specified, while in structural models, the behavior of the budget variable is considered a function of a number of other variables. Economic analysis of time profiles typically is based in the first instance on simple time-series models. Various kinds of diagnostic information from these models then can suggest whether more sophisticated models should be developed (see, for example, [1]).

Economic time-series analysis usually is based on the so-called ARMA (autoregressive moving average) model.[1] The autoregressive part of the model specifies the value of a variable y at time t as a function of its past values, with some random error:

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + \ldots + a_p y_{t-p} + \epsilon_t \quad . \tag{1}$$

where the errors ϵ are considered to be independent and identically distributed (iid), with zero mean and standard deviation σ. An autoregressive model of order (i.e., maximum lag) p is written AR(p).

The moving-average part of the model specifies the variable at time t as the outcome of random effects over time:

$$y_t = \epsilon_t + b_1 \epsilon_{t-1} + \ldots + b_q \epsilon_{t-q} \quad , \tag{2}$$

where the ϵ variables are specified as above. A moving average model of order q is written MA(q). The full ARMA model expresses the variable at each time t as the sum of the autoregressive and moving-average parts of the model, so that:

$$y_t = a_1 y_{t-1} + \ldots + a_p y_{t-p} + \epsilon_t + b_1 \epsilon_{t-1} + \ldots + b_q \epsilon_{t-q} \quad . \tag{3}$$

1. Most of the following discussion follows Chow [1]. Other good references are Box and Jenkins [2] and Amemiya [3]. It is assumed throughout that the time series y_t is stationary, i. e., has a constant mean and variance.

An ARMA model of autoregressive order p and moving average order q is written ARMA(p,q). Many common macroeconomic time series, such as the gross national product, are frequently modelled as AR(1) or AR(2).[1]

In general, the dynamic properties of the time series y_t are determined by some joint probability distribution of all of the y_t. However, for practical purposes, the first two moments of this distribution contain all of the useful information for analyzing its properties. The first two moments are represented by the autocovariance matrix of the series, defined as:

$$[\gamma_{ij}] = E(y_i - \mu)(y_j - \mu) \quad . \tag{4}$$

It turns out that this matrix can be expressed iteratively as the solution to a difference equation of order p. Therefore, the dynamic properties of the time series in general are determined by the eigenvalues of the autocovariance matrix and are cyclic because of the cosine representation of complex conjugate roots. (Readers interested in additional details are referred to [1] or [2].)

The important point for this analysis is that the structure (if any) of a stationary time series can be discerned by examining the autocovariance matrix (or, more conveniently, the autocorrelation matrix) of the time series. After appropriately transforming the series to eliminate pure time trends, the autocorrelations between lagged values of different lengths will determine the degree of the ARMA(p,q) model.[2] In identifying time series models, both the autocorrelations and the so-called *partial autocorrelations* generally are used. (The partial autocorrelation is the standardized regression coefficient of y_{t-p} in the regression of y_t on $y_{t-1} \ldots y_{t-p}$.) If the partial autocorrelation abruptly becomes insignificant after p periods, an AR(p) model is probably reasonable. If, on the other hand, the simple autocorrelations terminate abruptly after q periods, an MA(q) model may be required. Finally, it may be the case that no ARMA(p,q) structure seems to represent the series very well, and a different kind of statistical model must be specified.

---

1. The order of the model obviously is sensitive to the time units measured. Most economic time series are annual in their order of autoregressivity, so that they are AR(1), AR(4), or AR(12), depending on whether time is measured in years, quarters, or months.

2. Another time series technique that imposes less formal structure is spectral density analysis This method is based on the Fourier analysis of the autocorrelations of the time series, and can help identify cycles of different lengths. Unfortunately, this so-called time-domain analysis requires large numbers of observations, which are not available in this case.

RESULTS OF TIME-SERIES ANALYSIS

As remarked above, the basic approach used in this analysis was to compute the autocorrelations among elements of the R&D time series by lag length, and examine the pattern of the autocorrelations for evidence of internal structure. All of the budget time series are strongly nonstationary: they exhibit pure time trends upward that contaminate the autocorrelations among lags of various lengths. Therefore, prior to analysis the R&D and total DON series were differenced once to remove these effects and to leave the differenced series approximately covariance-stationary (i.e., with no pure time trend).[1]

However, it was apparent that even after this first-differencing, both the total DON budget and the R&D budget series remained nonstationary (i.e., had some pure time dependence). Therefore, additional preliminary analysis was required before the formal time-series analysis could be undertaken. First, there is a strong suggestion from figure 6 that the R&D budget series may be closely bound to the total DON budget, yet that the R&D *share* of the total budget may be substantially independent of external events. Therefore, it was important to examine the R&D budget series as the composition of an R&D share series and the total DON budget series:

$$RD_t = \frac{RD_t}{DON_t} DON_t \quad . \qquad (5)$$

Second, it is obvious from the graphical analysis in the last section that major institutional changes occured over the period, in which the series shifted upwards more or less discontinuously to a higher level. Therefore, it was necessary to identify relatively "steady-state" time periods over which the time series of interest could be considered stationary.[2]

Finally, for forecasting purposes, it must be assumed that the total DON budget will remain a key policy variable in the DOD and overall federal budgets, and therefore that the internal structure of the historical DON budget series (if any) is of only limited use in forecasting future budgets.

1. First-differencing a series is a common technique for removing nonstationarity. One could also regress each series on a time variable and use the residuals in the autocorrelation analysis [1, p. 204].

2. This not to suggest that recent history is somehow uninteresting or less important than the preceding 25 years, but only that statistically it generally is not possible to discern the internal structure of a series when such jumps are included in the data.

For all of these reasons, the time-series analysis of Navy R&D budgets was based on the share of the total DON budget accounted for by R&D. As figure 7 shows, the (first-differenced) R&D budget varies about 10 after the "takeoff" years 1955-1959. Thus, a stationary model is analyzed using the data from 1960 to the present.

Figure 8 presents the autocorrelation and partial autocorrelation functions for the R&D budget share series. The gradual decay of the autocorrlation function and the abrupt termination of the partial autocorrelation function after one period strongly suggest an AR(1) model.

Using Box-Jenkins notation, this AR(1) model can be parameterized as:

$$(1-\phi L)((\frac{RD}{DON})_t-\alpha)=\epsilon_t \quad , \tag{6}$$

where ϕ is an autoregression parameter, L is the lag operator, α is the mean of $\frac{RD}{DON}$, and ϵ_t is iid as $N(0,\sigma^2)$. An alternative parametrization is:

$$(1-\phi L)((\frac{RD}{DON})_t-\alpha-\beta t)=\epsilon_t \quad , \tag{7}$$

where βt is a pure time trend in the R&D budget share. Table 1 compares maximum-likelihood estimates from equations 6 and 7. The mean R&D budget share is 10.1 percent, with an autoregression parameter of 0.82. There is no evidence of a pure time trend. Figure 9 presents an out-sample forecast of the R&D budget share based on these parameters with the upper and lower 95-percent confidence limits.

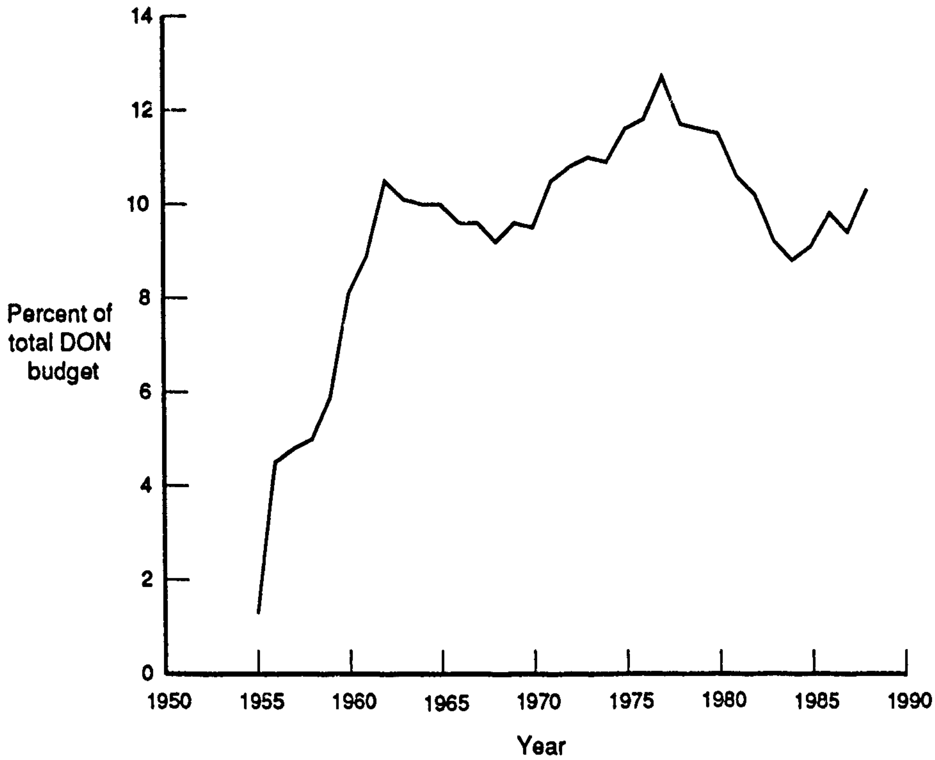

Figure 7. R&D share of DON budget

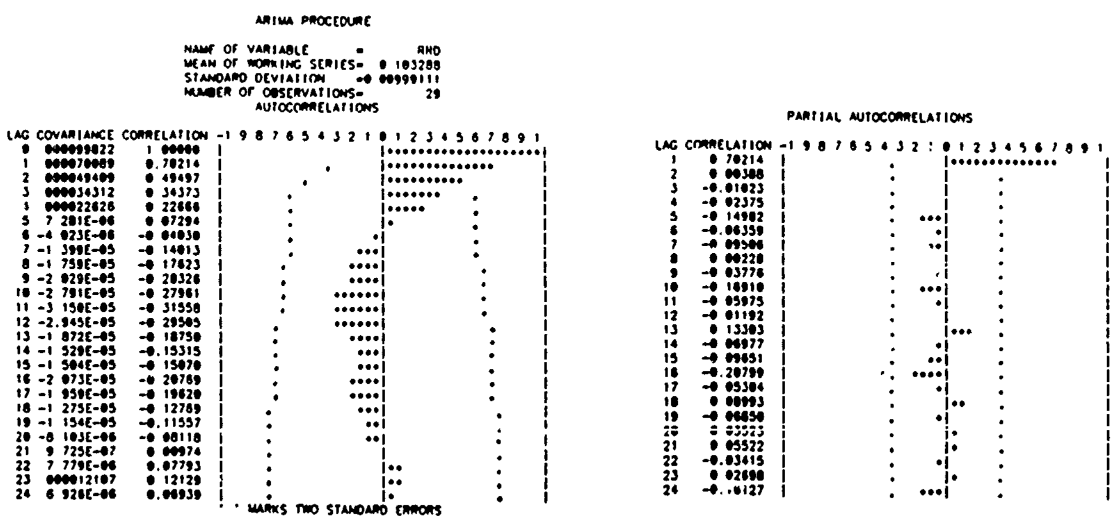

Figure 8. Autocorrelation and partial autocorrelation functions

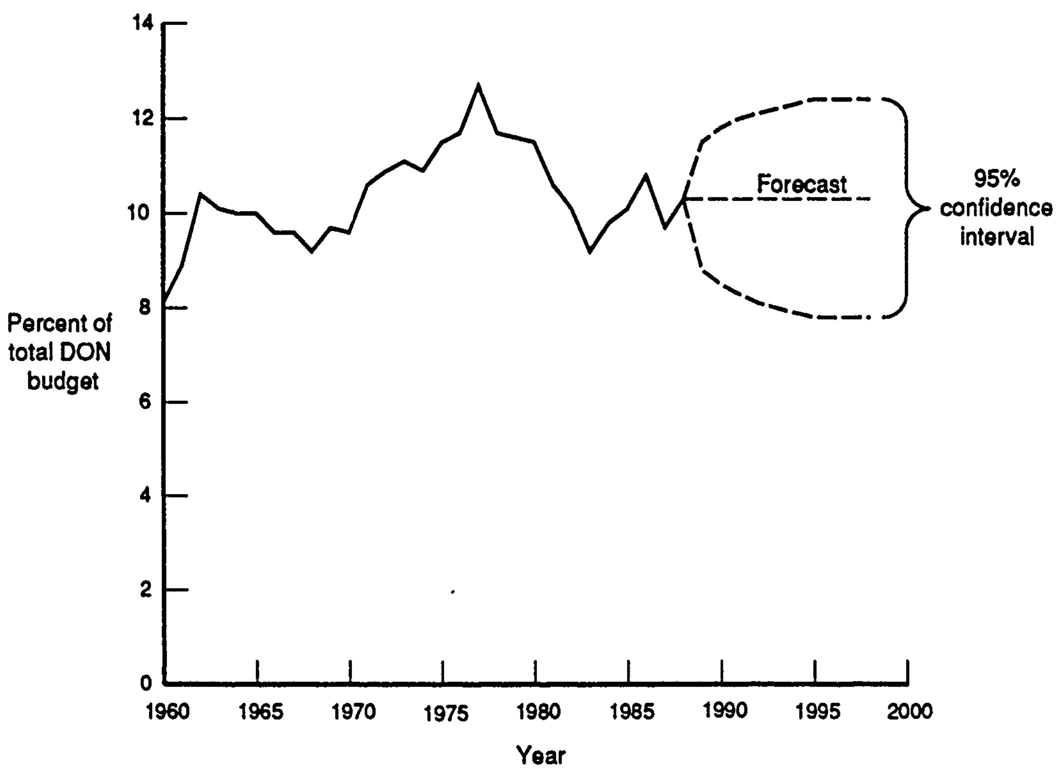

Figure 9. Out-sample forecast of R&D budget share

Table 1. Estimates of parameters

Variable	Equation 6 parameters[a]	Equation 7 parameters[a]
Mean (α)	0.101	0.057
	(17.71)	(1.63)
Slope (β)		0.001
		(1.29)
Autoregression (ϕ)	0.816	0.772
	(7.95)	(6.33)
Standard error (σ)	0.007	0.007

a. T-statistics are in parentheses.

CONCLUSIONS

What, then, is the interpretation of the results presented in the fourth section, Results of Time Series Analysis?

First, R&D budgets probably can be forecast fairly reliably as a constant share of the total DON budget. The advantage is that independent forecasts of the aggregate DON budget can be used to generate alternative R&D budget forecasts. It may well be unwise in any case to divorce forecasts of the R&D budget from forecasts of the aggregate DON budget, particularly in the current climate of budget austerity. Probably the safest assumption to make is that the R&D budget share will remain constant at about 10 percent of the DON total.

Second, one probably should be cautious in using recent budgetary history as a guide to future DON budget *levels*. Another surge in spending such as that witnessed in the early 1980s can hardly occur again in the current macroeconomic climate of large deficits. On the other hand, the *composition* of the DON budget by functional activity seems to have been unaffected by recent events. Therefore, data from the 1980s probably can be used in analyses based on budget shares without much concern.

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[3] T. Amemiya. *Advanced Econometrics.* Harvard University Press, 1985

APPENDIX

DATA USED IN ANALYSIS

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Table A-1. DON budget data (millions of current-year dollars)

Fiscal year	Aggregate DON budget	DON manpower budget	DON O&M budget	DON Procure-ment budget	DON R&D budget
55	10,323.3	3,243.1	3,540.3	3,674.7	60.2
56	9,496.4	3,910.8	2,394.8	3,756.7	433.9
57	9,359.0	3,145.2	2,447.9	3,316.0	430.0
58	9,943.6	3,218.8	2,730.1	3,494.8	499.9
59	10,284.7	3,085.9	2,670.2	3,923.2	600.3
60	11,441.3	3,263.3	2,752.1	4,504.0	922.0
61	11,532.4	3,295.9	2,775.3	4,435.0	1,026.1
62	11,948.6	3.359.6	2.767.9	4.572.0	1.249.1
63	13.735.6	3,519.7	3,186.0	5.651.2	1,379.6
64	15,842.3	3,553.4	3,142.2	6,849.1	1.499.8
65	14.686.5	3,904.6	3,294.9	5,948.8	1.458.2
66	14.559.1	4,040.6	3,408.9	5,714.8	1,394.7
67	16,851.6	4.821.1	4,140.4	6,324.8	1,565.4
68	19.968.1	5,591.3	5,063.0	7,477.3	1,839.8
69	22,161.0	5.913.9	5.913.0	8,204.3	2,129.8
70	22,503.1	6,246.0	5.788.8	8.313.3	2.150.0
71	20.547.1	6.065.9	5.212.4	7,103.8	2.165.0
72	20,892.0	5.829.0	5.306.0	7,497.0	2.260.0
73	22.121.8	6.785.5	5,460.9	7,422.6	2,442.8
74	23,539.6	7,062.5	5.950.8	7,967.0	2.559.4
75	25,817.1	7,741.1	7,360.0	7,713.4	3.002.6
76	27.603.5	7,882.2	8,764.9	7,707.5	3.248.9
77	31.605.1	8.177.5	9.702.7	9,718.1	4.006.8
78	34.192.0	8,396.4	11,370.2	10,433.1	3,992.1
79	36.019.4	8.638.4	12,619.3	10,578.2	4,183.6
80	38,158.7	9,149.4	13,154.9	11,440.3	4,414.1
81	44,015.9	10,030.4	16,099.8	13,232.3	4,653.3
82	55,171.4	12,393.0	20,333.6	16,872.4	5.572.3
83	64.713.3	14.529.0	23,185.7	21,055.9	5,947.7
84	73,275.3	15.596.4	24.613.7	25.021.0	7,139.2
85	85.807.5	21,949.2	26.514.0	28,724.9	8,619.4
86	92.491.9	23.860.4	27,749.3	30,873.0	10.001.7
87	88.809.9	24.427.1	27,332.9	28,473.6	8.568.8
88	92,655.5	25.330.8	26.639.8	31,108.9	9.523.4

Table A-2. DON budget data (millions of 1972 dollars)

Fiscal year	Aggregate DON budget	DON manpower budget	DON O&M budget	DON Procurement budget	DON R&D budget
55	16.968	5.010	5,819	6,040	99
56	15,124	4.636	3,814	5,983	691
57	14.414	4.844	3,770	5,107	693
58	15.057	4,874	4,134	5,292	757
59	15,214	4.565	3.950	5,811	888
60	16.654	4.750	4,006	6,556	1,342
61	16,634	4.754	4,003	6,397	1,480
62	16,922	4.758	3,920	6,475	1,769
63	19,165	4,911	4,444	7,885	1,925
64	20,671	4,883	4,318	9.412	2,061
65	19,643	5.251	4,431	8,000	1,961
66	18.967	5.264	4,441	7,445	1,817
67	21,315	6,098	5,237	8,000	1.980
68	24.192	6.774	6,140	9,059	2.229
69	25.534	6.814	6,813	9,453	2,454
70	24,607	6.830	6.330	9,096	2,351
71	21.401	6.318	5.429	7,399	2.255
72	20.892	5.829	5,306	7,497	2.260
73	20.919	6.426	5.164	7,019	2,310
74	20,455	6,137	5,171	6,923	2.224
75	20,524	6.154	5,851	6,132	2.387
76	20.858	5.956	6.623	5,824	2.455
77	22.567	5.839	6.928	6.939	2.861
78	22,731	5.582	7,559	6,936	2.654
79	22,041	5.286	7,722	6,473	2.560
80	21.387	5,128	7,373	6,412	2,474
81	22.503	5.128	8,231	6.765	2.379
82	26.604	5,976	9,805	8.136	2.687
83	30,054	6.747	10,767	9.778	2.762
84	32.803	6.982	11,021	11,604	3.196
85	35,978	9.203	11,117	12.044	3.614
86	37,721	9.731	11,317	12,593	4,079
87	35.270	9,701	10,855	11,310	3,403
88	35.473	9.717	10,199	11,910	3,646

Table A-3. DON budget data (millions of 1980 dollars)

Fiscal year	Aggregate DON budget	DON manpower budget	DON O&M budget	DON Procure-ment budget	DON R&D budget
55	5,786.0	1,708.4	1,984.2	2,059.6	33.76
56	5,322.5	1,631.5	1,342.2	2,105.6	243.18
57	5,245.5	1,762.8	1,372.0	1,858.5	252.19
58	5,573.2	1,804.1	1,530.1	1,958.8	280.19
59	5,764.3	1,729.6	1,496.6	2,201.7	336.45
60	6,412.6	1,829.0	1,542.5	2,524.4	516.73
61	6,463.6	1,847.3	1,555.5	2,485.7	575.09
62	6,696.9	1,883.0	1,551.3	2,562.5	700.08
63	7,698.4	1,972.7	1,785.1	3,167.3	773.26
64	8,430.8	1,991.6	1,761.1	3,838.8	840.60
65	8,186.6	2,188.5	1,846.7	3,334.2	817.28
66	8,160.0	2,264.7	1,910.6	3,203.0	781.71
67	9,444.9	2,702.1	2,320.6	3,544.9	877.36
68	11,191.6	3,133.8	2,840.5	4,190.8	1,031.17
69	12,420.7	3,314.6	3,314.1	4,598.3	1,193.72
70	12,612.4	3,500.7	3,244.5	4,662.2	1,205.02
71	11,516.1	3,399.8	2,921.4	3,981.5	1,213.44
72	11,709.4	3,267.0	2,973.9	4,201.9	1,266.67
73	12,398.7	3,808.7	3,060.7	4,160.2	1,369.14
74	13,193.4	3,958.3	3,335.3	4,465.3	1,434.47
75	14,469.9	4,338.7	4,125.1	4,323.2	1,682.89
76	15,471.1	4,417.8	4,912.5	4,319.9	1,820.95
77	17,713.9	4,583.3	5,438.1	5,446.7	2,245.73
78	19,163.8	4,706.0	6,372.7	5,847.5	2,237.50
79	20,188.0	4,841.6	7,072.8	5,928.8	2,344.78
80	21,387.0	5,128.0	7,373.0	6,412.0	2,474.00
81	24,669.8	5,621.8	9,023.6	7,416.4	2,608.07
82	30,922.2	6,946.0	11,396.5	9,456.6	3,123.14
83	36,273.0	8,143.1	12,995.0	11,801.3	3,333.53
84	41,069.0	8,741.4	13,798.2	14,528.1	4,001.36
85	48,093.0	12,302.0	14,860.5	16,099.6	4,830.96
86	51,839.4	13,373.2	15,552.8	17,306.4	5,605.71
87	49,775.7	13,690.8	15,319.4	15,961.5	4,802.57
88	51,931.1	14,225.3	14,930.9	17,435.8	5,337.60